

Exhibit 1

DECLARATION OF JAMES J. GUSEK, P.E.

I, James J. Gusek, hereby declare as follows:

1. My name is James J. Gusek, P.E. I am 69 years of age and have personal knowledge of the matters set forth in this declaration.
2. I graduated from the Colorado School of Mines in 1973 with a Bachelor of Science degree in mining engineering. Most of my 40-plus year career has involved remediation of mining sites, ranging from coal mines to metal and non-metal mines. This experience includes a number of challenging mine land reclamation projects that included geotechnical investigations, development of grading and reclamation plans, and the design of constructed wetlands for treating polluted mine water. I am an internationally recognized authority in the passive treatment of mine drainage. One of my passive treatment projects garnered several awards for engineering excellence. I am also the co-chair of the Mitigation Group of the Metal Mining Sector of the Acid Drainage Technology Initiative (ADTI) and I am the editor/co-author of a book on the prevention and treatment of metal mine drainage, which is equally applicable to coal mine drainage.
3. Recognizing that active or passive treatment of mine drainage in perpetuity is unsustainable, I have also focused my engineering efforts on developing technologies that prevent acid rock drainage (ARD)--i.e., source control. Source control is the primary remediation issue at the former Maxine Mine site.

Some of these proven technologies are over 30 years old. Capitalizing on my knowledge of these technologies, I am the co-inventor of a patented process for delivering ARD-suppressing materials using foam as a transport medium (US Patent No. US8985902B2).

4. I have presented dozens of technical papers and short courses at mining-related conferences over my career, and I was selected as a 2013 Henry Krumb distinguished lecturer by the Society for Mining, Metallurgy, and Exploration (SME). I also received the Environmental Stewardship Distinguished Service Award from SME in 2015. This honor, bestowed upon me by my engineering peers, is viewed as a lifetime achievement award in recognition of my research, development, and implementation of innovative mined land reclamation and passive mine water treatment technologies.

5. I have co-authored three books, published 14 peer-reviewed technical papers and eight magazine articles on mine remediation and other mining related topics. My publications include 51 papers and presentations included in mining conference proceedings. Many of these papers or presentations are available for downloading from the ResearchGate platform:

<https://www.researchgate.net/profile/James-Gusek/publications>

In particular, the following peer reviewed paper is germane to the Maxine remediation situation: Gusek, James, 2016. *A Pathway to Walk-Away? – 30-Year-*

Old Technology to Suppress Acid Rock Drainage Revisited. Oral Presentation and Proceedings - Tailings and Mine Waste 2016, October 3-5. Keystone, CO (attached hereto as Exhibit A).

6. My relevant experience in remediating sites with issues similar to the ones exhibited at the former Maxine Mine site include:

Confidential Site Open Pit Gold Mine Source Control Testing, North America

A major North American gold mine intends to expand operations over the next several decades. In the process, the mine will produce several hundred million tons of potentially acid generating (PAG) mine waste containing about 8.5 percent pyrite and no alkalinity. This is about ten times the concentration of pyrite in the Maxine material. Eventually, the PAG will be backfilled into the pits and be submerged beneath the rebounding groundwater levels. However, before it is backfilled, the PAG is predicted to produce a significant amount of ARD due to bacteria-enhanced pyrite oxidation. I was the lead technical advisor who developed the work scopes for a 32-week kinetic cell test (KCT) treatability program at a partnered laboratory to determine if an antibacterial technology could be used to curb ARD production. Antibacterial applications included sodium lauryl sulfate (the active ingredient in shampoo), milk, and alkaline amendments alone and in combination. While the test work was interrupted by the Coronavirus Pandemic, results of the KCTs receiving

milk showed the most promise and this knowledge/technology has been and is being applied to the situation at the former Maxine Mine.

Barite Hill Gold Mine Superfund Site Tier 1 Treatability Testing, US EPA/Black and Veatch, South Carolina

Groundwater passing through an acid-generating mine waste dump at this Superfund site is delivering a steady load of heavy metal acidity to a pit lake which has re-acidified after repeated neutralization attempts. Bacteria-enhanced pyrite oxidation in three distinct zones of the mine waste was thought to be the source of the loading. Working as a subcontractor for the EPA from 2016 to 2018, I was the lead technical advisor who developed the work scopes and evaluated the data from a series of Tier 1 treatability tests to determine if an antibacterial technology could be used to curb the metal loading on the pit lake. Antibacterial applications included sodium lauryl sulfate, milk, and alkaline amendments alone and in combination. Treatment was successful in eliminating the acidophilic bacteria in all zones replicated in the test units, but no single approach was capable of treating the entire dump. Pilot testing of the most promising technologies is pending. Contaminated groundwater conditions at this Superfund Site are very similar to the groundwater conditions at the former Maxine Mine in the lower and upper sediment basins. Consequently, the remedies identified in this prior study for the EPA form the foundation of the remedies being considered at the former Maxine Mine.

Atlas Tailings/Brewery Waste Kinetic Cell Testing, Ouray County, Colorado

Acidic Atlas tailings are a source of heavy metal contamination in Sneffels Creek. This fine-grained pyrite-bearing mine waste is similar to the materials at the former Maxine Mine. I advised a Colorado-based non-profit called Beer2Clear (B2C) in advancing the concept of using spent brewery grain (SBG) to suppress the microbial oxidation of pyrite in mine wastes, including tailings. In a 20-unit set of KCTs started in January 2020 for B2C, different amounts of SBG from a local brewery were mixed with the tailings. The SBG decay products were expected to suppress ARD formation. Final results (fall 2020) showed that all the KCTs that received SBG generated leachates with pHs near or above 8.0 while the two control KCTs produced leachate from 4.5 pH (un-vegetated) to 6.1 pH (vegetated). The findings from this prior study influenced the inclusion of SBG in the remediation plan for portions of the former Maxine Mine and in kinetic cell tests that I designed for Maxine.

7. A general overview of the remediation process at the former Maxine Mine is similar to the approach a medical doctor follows with a new patient. The similarity is remarkable because the “patient,” the former Maxine Mine, suffers from a chronic bacterial infection. Basically, a common bacterium *Acidithiobacillus Ferrooxidans*, attacks the pyrite (fool’s gold) that occurs in mine waste at the site. Fortunately, a number of common materials have been found that can kill this bug,

including milk (diluted) and the active ingredient in shampoo. Also, the organic acids generated in the root zone of the site vegetation are antibacterial. Thus, the healthy forest that covers most of the site contributes to preventing pyrite oxidation and acid rock drainage generation. Evidence of natural attenuation processes has been observed in some of the data collected to date, i.e., relatively low concentrations of pyrite close to the surface of the site compared to deeper horizons.

8. Following the medical analogy, the following steps are required to remediate the site:

- Diagnose the patient, or site characterization. This involves collecting samples for biopsy and for the presence/absence of pyrite and accompanying microbes. It also involves drilling monitoring wells (which has been completed) and measuring ground water levels, akin to measuring pulse and blood pressures. It might also involve installation of certain “real time” monitoring devices such as lysimeters and moisture content probes that accumulate patient data over a recommended time span to better identify symptoms. These monitoring devices have also been recently (August 2021) been installed.
- Conduct small scale clinical trials. This involves testing of various remedial approaches to make sure the remedy selected **“DOES NO HARM”**. Experience has shown that all mine sites (like patients) are different; a given remedy is not universal and may actually harm the patient if the treatment isn’t tailored to the situation. Small scale trials (bench scale tests) can take from four to six months to complete. Some tests were commissioned in late 2020 and concluded in early 2021; other tests may yet be conducted to verify the applicability of using commercially available alkalinity producing materials to neutralize acidity levels in the seeps.
- Conduct large scale clinical trials. In mine site remediation, this might mean vegetative test plots (which can improve groundwater chemistry) and the measuring of effects of treatment in groundwater seeps. Field

trials should be conducted over at least a year to measure the site responses to seasonal changes. Some Maxine field trials (e.g., in the lower sediment basins) began in October 2020 and their effects are still being monitored.

9. For complicated mine sites such as the former Maxine Mine, developing a “Conceptual Site Model” (CSM) is part of the diagnostic process. All the data from testing, monitoring, and results from clinical trials (large and small) is compiled in a way that typically reveals a set of possible remedial strategies that make sense. As with any disease, non-invasive remedies are preferred over disruptive approaches that can harm the patient. Due to site specific conditions, such as the depth to groundwater, more than one conceptual site model may be required. This is indeed the case at the former Maxine Mine, and data necessary to define the CSMs is still being collected and assessed as of the date of this declaration. As discussed below, data collection for the more advanced clinical trials has begun in relevant portions of the site, but it is early in the process.

10. The design focus is on “arthroscopic” and “topical” based remedies; their development is underway. Invasive remedies that destroy or disrupt the site ecologically and environmentally — for example, in ways that result in the removal of the mature 50-year-old forest — are possible. But similar to open heart surgery and amputation, they are the remedies of last resort for the former Maxine Mine. Conservative strategies should be tried first if the remediation is to be done in an

ecologically and environmentally responsible manner and if there is to be a basis for regulatory approval.

11. I have been involved with the remediation team of scientists and engineers since July 2020. The team's and my understanding of the site has evolved over this interval and continues to evolve as more data is collected and assessed. Some portions of the site were remediated following a "triage" strategy to mitigate adverse effects of pyrite oxidization using well-established best management practices. However, long term patient/site recovery and remission is the collective goal. To summarize, the site was sub-divided into various features/groups:

- Groundwater Seeps 1 through 6.
- The "Main Pile" of mine waste, most of which has naturally been reforested since its placement 50 years or more ago. Two small portions of the pile (about 2 acres) are sparsely vegetated with "pioneer" pine tree vegetation intruding; these areas exhibit features similar to erosion gullies, but active erosion appears to be limited to brief but severe storm events. The materials in the pile contain pyrite and appear to contribute to the acidity observed in seeps 1, 2, 4, 5, and 6.
- Two "Sediment Ponds" that appear to be filled with the materials transported from the two erosion gullies described above. These materials also contain pyrite and appear to contribute to the acidity in Seep 3.

12. Data collected to date suggest that the following remedial technologies can be effective for the features or groups:

- Iron terraces (a low-maintenance passive treatment technology) would be constructed at Seeps 1, 2, and 6.

- An additional passive treatment system would receive Seep 6 water.
- Minor flows, on the order of several gallons per minute (less than a garden hose) from Seeps 4 and 5 would be mitigated with a lined channel filled with acidity-neutralizing limestone cobbles. This is a well-accepted best management practice for low flows. This remedy has already been implemented.
- Poorly vegetated portions of the Main Pile would be revegetated. This effort would include regrading and applying appropriate soil amendments to encourage plant growth. The natural organic bactericides generated in the plant root zones would reduce pyrite oxidation sustainably. Based on site experience, the pine forest surrounding the barren areas would invade and replace the grass species.
- Poorly vegetated portions of the Sediment Basins would be revegetated.
- Runoff/run-on would be diverted away from the erosion gullies; a sediment collection “check dam” would be installed at the bottom of the gully; if needed, the channel invert of the gully may receive a drainage layer that would prevent future sediment transport. Natural invasion of tree species would permanently stabilize the sides of the gully.
- Bactericides designed to mitigate pyrite oxidation would be applied (in a one-time application) to portions of the Main Pile believed to be generating ARD that is observed in Seeps 1, 2, 4, 5, and 6.
- Liquid alkalinity would be delivered to neutralize water already affected by pyrite oxidation. In saturated portions of the site (Sediment Basins), this technology should mitigate future pyrite oxidation which is affecting the chemistry in Seep 3 (next to Locust Fork). Liquid alkalinity may be generated by passing clean rainfall/runoff through a zone of a commercially available alkalinity product. Prior to its implementation, screening tests are needed to validate its applicability. Tracer tests to confirm the groundwater

connectivity between the upper Sediment Basin and Seep 3 are being assessed.

- Ground water diversion in the Sediment Basin area could permanently mitigate future pyrite oxidation in the saturated zone. This remedy may be coupled with passive treatment. Adopting this option depends on the future collection and interpretation of ground water monitoring data.

13. The remediation plan was and is still being developed based on sound science and engineering principles, supported by bench scale test results and team member personal experience, some of which spans five decades. Foremost, the overall plan is to **DO NO HARM**. Its implementation is intended to be completed in phases which have sometimes been delayed by inclement weather.

14. The following remediation activities have been implemented:

- The Sediment Basins were revegetated in October to December 2020. This revegetation activity was originally intended as a test plot; SBG was used in one of the two sediment basins as an ARD suppressant. Its assessment is underway.
- Poorly vegetated portions of the Main Pile were revegetated in July 2021. It is expected to produce improvement in the chemistry of Seeps 1, 2, and possibly Seep 6.
- Check dams were constructed below both erosion gulleys. These appear to be functioning as designed.
- Seep 4 and Seep 5 flows were diverted into limestone rock lined channels (which are also lined with geomembrane). These are called open limestone channels (OLCs), which are a best management practice adopted by many state agencies and watershed groups throughout Appalachia.

- Bench scale passive treatment tests were conducted.
- Kinetic cell tests (26 test units in total) to suppress ARD using antibacterial strategies were monitored for six months (from October 2020 to March 2021). The test results will be used to design/select the bactericide recipe for application in a field demonstration area near Seeps 1 and 2. Weather and conditions permitting, this test should be conducted in the fall of 2021.
- Six additional monitoring wells were drilled in mid-July 2021 to better characterize the site's ground water conditions. Drill cuttings from each new monitoring well were collected every five feet and tested for metals (e.g., iron) content, bacterial counts, pyrite content, and leachability using standard test protocols. Bacterial count testing is ongoing as of the date of this declaration. Preliminary assessment of available data is underway. The compiled results will be used to design the bactericide field demonstration near Seeps 1 and 2 as previously discussed. An additional aquifer slug test is scheduled for late August.
- Lysimeters, a means for measuring unbiased infiltration of rainwater into soils and into the pyrite-bearing coarse coal refuse, were recently installed in four different portions of the site. The data from these is typically collected for a full year to measure the effects of surface vegetation and evapotranspiration on infiltration rates. Double ring infiltrometer tests were also conducted at the same time. These data, coupled with the analytical data from the monitoring well drill cuttings, will be used to design the bactericide application strategy.

15. In summary, the remediation team has collected much data in the spring and summer field season and in some cases, preliminary mitigation measures have been implemented (e.g., OLCs, check dams, revegetation, ARD suppression amendments were added to the lower sediment basin in 2020).

16. Work toward a site-wide remedy is still ongoing. The following activities are included in this effort:

- Collect and analyze the water level and chemistry data from the new monitoring wells.
- Design and conduct the bactericide application field test.
- Assess the potential use of various commercial products to produce alkalinity (DO NO HARM).
- Construct simple surface water runoff control structures called “water bars” to divert stormwater away from the two gully areas and into the mature forest.
- Monitor the new lysimeter installations (ideally for a year).
- Monitor the effects of the revegetation of the recently seeded area on the chemistry of Seeps 1 and 2, which are immediately downgradient.

17. As expected with every engineering or site investigation project, some surprises have been encountered. In particular, after the remediation/revegetation of a portion of the site, a previously undetected seep of acidic water was discovered. The flow contribution of this upwelling, whose source is unknown at this time, compromised the beneficial effects of the OLCs on the Seep 4 and Seep 5 discharges. The discovery occurred in February 2021 and the source of and reasons for this seepage are being investigated. The patient appears to have a new symptom. The seep appears to be rainfall-related; it remains to be seen if it will dry up after a prolonged interval of relatively dry weather.

18. Why is additional time necessary?

- Returning to the medical analogy, some triage measures have been implemented but the full diagnosis/conceptual site models have yet

to be finalized. New monitoring well data are just beginning to be collected and lysimeter data collection will begin shortly. The goal of all this effort is to identify the best treatment strategy for the patient/site and to DO NO HARM. A more aggressive strategy will not constitute a scientific approach driven by reliable and sufficient empirical data. It also would present a significant risk of exacerbating, rather than remediating, the patient's condition.

- While an additional full year of monitoring well and lysimeter data would be ideal, a partial dataset spanning six to nine months would be the bare minimum to provide a detailed site-wide remedy plan. At the very least, resolving the surprise seepage as discussed in paragraph 17 could take several months as the situation characterization efforts are weather dependent. Other investigation technologies are being considered.
- To the extent that certain low risk/large benefit remediation activities can be completed earlier, the intention is that they will be, but a full site wide remediation design with a low risk of doing no harm is probably a year in the future.

I hereby state under penalty of perjury that the statements above are true and correct.

Date: August 27, 2021.



James J. Gusek, P.E.

Exhibit A

A Pathway to Walk-Away? – 30 Year Old Technology to Suppress Acid Rock Drainage Revisited

J. J. Gusek

Linkan Engineering, Golden, Colorado, USA

ABSTRACT: Patented controlled-release bactericide pellets formulated in the 1980s, coupled with surface-applied bactericide, were used at dozens of acid rock drainage (ARD) prone sites across the USA and internationally. In the late-1990s, usage of this technology virtually ceased when the sole vendor of the bactericide products closed its doors. The primary goal of these products was facilitating revegetation on acid generating mine wastes; decreases in ARD flow, metals/acidity loading, and sulfate were secondary benefits. At the time, state agencies and mining companies alike viewed bactericide applications as temporary remedies. In hindsight, were they right? This paper considers available data for selected sites to assess the long-term conditions two or more decades after bactericide applications. The paper also examines several promising 21st century technologies that might capitalize on this earlier work and be combined with bactericides to fashion a practical “Pathway to Walk-Away” for mining companies and government agencies which are saddled with ARD treatment in perpetuity.

1 INTRODUCTION

1.1 *Background*

The bacterial component of acid rock drainage (ARD) formation was first recognized in the early 1950s by Leathen et al. (1953) and subsequent research that appears to peak in the 1980s and 1990s revealed that many common surfactants such as sodium lauryl sulfate (SLS), sodium dodecylbenzene sulfonate (SDS), alkyl benzene sulfonate (ABS), biosolids, and other organic materials significantly inhibited bacterial activity with respect to *Thiobacillus-ferrooxidans* also known as *Acidithiobacillus-ferrooxidans* [ATFO].

In particular, Kleinmann and Erickson (1983) published a compendium of research findings on this topic in US Bureau of Mines (USBM) Report of Investigation No. 8847. The authors provided five conclusions:

1. *Thiobacillus ferrooxidans* plays an important role in determining the rate of pyrite oxidation. Anionic surfactants, applied at concentrations greater than 25 mg/L, reduce this bacterial activity and thereby slow acid production.
2. A laboratory procedure has been developed to determine suitable application rates for a specific site. Based on existing field data, the procedure appears to be effective in preventing overtreatment. Surfactant concentrations have generally been less than 0.1 mg/L in the effluent from the treated areas.
3. Sodium lauryl sulfate was applied to an 11-acre (4.45 ha) inactive coal refuse pile in southern West Virginia at a material cost of about \$US200 per acre (\$US500/ha). Acid production fell approximately 60-pct, with an associated 90-pct decrease in iron concentration.

4. An 8-acre (3.2 ha) active coal refuse area in northern West Virginia was similarly treated. Acid production fell approximately 95-pct, with an associated 95-pct decrease in iron concentration.
5. At sites where water treatment costs are high, application of an anionic surfactant should be considered. Surfactant application should be repeated three times a year for maximum benefit.

In the mid- to late-1980s and the decade following, bactericide usage focused on facilitating revegetation of pyritic coal mine wastes (e.g., coarse coal refuse) and minimizing acidic drainage from pyritic shale partings in surface mine backfill. A summary of the advances and state of the art was provided by R. Kleinmann in Brady, Smith, and Schueck, eds., 1998 (Chapter 15). The development of controlled-release pellets containing SLS was one key advance in the ATFO bactericide technology since the publication of USBM RI No.8847 in 1983. The commercially available product called “ProMac” which evolved through two formulations (Kleinmann in Brady et al., 1998) was typically applied in the following manner:

1. The exposed mine waste surface received agricultural lime or other alkaline amendments to neutralize stored acidity;
2. A 2% solution of SLS was sprayed on exposed pyritic mine waste with a hydroseeder unit;
3. Slow-release ProMac pellets were applied; these dissolved at various rates to basically deliver an SLS solution with a steady concentration of about 465 mg/L dissolved in infiltrating rainfall or snowmelt (Sobek et al., 1990); and
4. A final lift of topsoil or plant growth media as thin as 100 mm was placed and revegetated.

The revegetation step appeared to be a key step in the success of ATFO suppression process; otherwise, SLS reapplications as frequent as three times per year were recommended (Kleinmann, op cit.). Verburg et al. (2003) observed positive results with the application of a 1% SLS solution to suppress ARD formation in a metal mine tailing containing 60% by weight pyritic sulfur. Verburg et al. observed the following trend: “...the supernatant from the bactericide-amended samples without exception has the highest values for pH and lowest values of specific conductance, acidity, and sulfate with each material group [tested]”. After 30 weeks of observation, the positive effects of SLS application were still evident but were rightly considered temporary.

Other non-surfactant organic amendments were found to be effective in suppressing ATFO including:

- composted sewage sludge (Pichtel & Dick, 1990),
- composted paper mill sludge (Pichtel & Dick, 1990),
- pyruvic acid (Pichtel & Dick, 1990),
- a water-soluble extract from composted sewage sludge (Pichtel & Dick, 1990),
- spent brewery grain (Lindsay et al., 2010), and
- waste milk/dairy products (Jin et al., 2008).

In theory, any biodegradable organic matter, including biochemical reactor (BCR) effluent could be effective in suppressing ATFO (Gusek, 2015).

When biodegradable organic matter is included in the design, the ATFO suppression effects may last longer than SLS, SDS, or ABS alone, but they should still only be considered temporary. A robust plant community is recommended to sustainably suppress ATFO in the long term.

1.2 How Surfactant-Based Bactericides Work

The ATFO organism functions well in aqueous environments exhibiting pH values <2.0 (Baker and Banfield, 2003). To survive in this hostile environment, the microbes cloak themselves in a thick oily protein membrane which employs several protective mechanisms, including proton “pumps”, that allow the cells to maintain a circumneutral cytoplasmic pH (Goulbourne, et al., 1998). Surfactants such as SLS and SDS disrupt the protein membrane (Alexander, et al., 1987) resulting in the flooding of the cell protoplasm with the surrounding acidic fluid. In effect, the

microbe “stews in its own juices” and is destroyed. Due to the simple destruction mechanism involved, it is probably impossible for an ATFO cell to develop resistance strategies as do other common microbes in response to exposure to antibiotics.

1.3 Controlled Release Bactericide ProMac Availability

Kleinmann and Ericson (1983) observed that SLS concentrations on the order of 25 mg/L were required to suppress ATFO. But stored acidity and other factors can negate this effect and higher concentrations of SLS were needed to achieve the same antibacterial result. The authors developed a simple laboratory procedure to estimate the proper concentration to apply. However, research revealed that slowly releasing the SLS at an effective concentration of about 465 mg/L over a prolonged period of about three years provided significant benefits.

Controlled release pellets were developed by BF Goodrich (Zaburunov, 1987) and marketed under the trade name of “ProMac” for about 15 years (1985 to 2000) by MV Technologies Inc. (MVTI) of Akron, OH. When the owner of MVTI retired, the availability of ProMac and related products ceased. However, the beneficial effects of their usage appear to have continued well into the 21st Century.

1.4 Probiotic Bacteria Substitution Facilitated by Organic “Bactericides”

Darwinian forces can also be employed to suppress ATFO activity. If organic nutrients are available to a suite of introduced heterotrophic microbes, these microbes can out-complete the ATFO consortium for resources (i.e., oxygen and iron) and ATFO populations are thus decimated. As previously cited, common municipal biosolids and organic acids have been shown to suppress ATFO activity (Pichtel and Dick, 1990). The proteins in waste milk can provide a similar effect (Jin, et al., 2007). The EPA has used biosolids on at least five Superfund sites exhibiting acidic drainage issues (EPA Clue-In, 2011):

- California Gulch OU-11 (Upper Arkansas River), Lake County, Colorado
- West Page Swamp (Bunker Hill), Shoshone County, Idaho
- Palmerton Zinc Pile, Carbon County, Pennsylvania
- Sharon Steel, Mercer County, Pennsylvania, and
- Oronogo-Duenweg Mining Site, Jasper County, Missouri

However, while the biosolids may have provided a temporary inhibitory effect, the subsequent success of the vegetation on these sites appears to have played a major role in the sustainability of the overall process. That is, the organic acids generated by seasonal plant root degradation provide another antibacterial reagent that can suppress ATFO (Tuttle, et al., 1977).

This “probiotic” effect from microbial consortia that outcompete ATFO may be the key to why the benefits of some previous SLS and SDS applications appear to persist for decades.

1.5 A Definition of Success

It is likely that remediated mining sites will typically be purged from institutional memory as time passes. Once an ARD-related problem is fixed, a site’s seepage may no longer be sampled and analyzed; *Case Closed*. Prior to the introduction of the internet, bio-engineered remedies of ARD problems were only documented in paper format. Thus, as a successfully reclaimed mining site matures naturally, its engineering history is probably lost to the mists of time as project managers retire and old paper reports are tossed into the recycling bin or trash can, or relegated to off-site archives, never to be seen again. Fortunately, some agencies such as the USEPA have digitized their reports.

For the purposes of this paper, a long-term success is defined as a site or situation that satisfies the following conditions:

- A problematic mine site exhibiting ARD received an engineered dose of bactericide or other designed remedy intended to disrupt ATFO activity/pyrite oxidation kinetics;

- No evidence of ARD can be currently observed at the site through air photo imagery, and/or
- The site has been completed dropped from regulatory sampling efforts; it is no longer monitored or there is nothing to monitor.

One could argue that a particular site was destined to improve on its own eventually and ATFO suppression efforts were due more to the effects of alkaline amendments or other factors. Fortunately, many of the engineers and scientists addressed this issue and they included control plots in their projects.

The case studies that follow satisfy one or more of the success criteria to varying degrees and clearly demonstrate the long term sustainability of bactericide applications when coupled with the proper follow-up design.

2 CASE HISTORIES

Due to space constraints, and/or the relative availability of information and/or the opportunity to interview individuals who were either familiar with the site or had personally worked on the project, seven sites were selected for detailed discussion. Of course, the data is skewed toward successful sites as authors tend to avoid discussing failure.

Also, some exact site locations are lost in the mists of time or the wastes have been moved or reprocessed. The two sites cited by Kleinmann and Erickson (1983) fall into this category. Over three decades after the projects, R. Kleinmann (2016) could not recall the exact locations of the two sites described in USBM RI 8477. For example: the Raleigh County site is described in the following detail by Kleinmann and Ericson (1983):

The pile was formed of Beckley Seam refuse during the late 19th century by dumping from an aerial tramway. It is 1,500 ft. [457m] long, 450 ft. [137m] wide, and approximately 130 ft.[40m] high at its crest. Quality of the drainage from the pile has been monitored by Westmoreland Coal Co. for over a decade, thus providing a good baseline against which the effectiveness of the [SLS] method could be judged.

The exact location of this site is unknown. An active coal refuse disposal area under permit by the same mining company or affiliate was located (Schaer, 2016). Interpreting a 1996 black and white air photo image (Google Earth™) showing a forest lineation that could be a remnant of the aerial tramway suggests that the pile may have been adjacent to a rail loadout facility about 0.5 miles (0.8 km) northwest of the town of Eccles, WV (Lat. 37.79°N, Long. 81.26°W). However, a pile as large as the one described by Kleinmann and Erickson is obviously absent in recent images. It is likely that the pile was reprocessed in a co-generation plant and/or moved.

In addition, Kleinmann and Erickson (1983) reported that "...more than 50 mining companies are using the technique with varied success on "... coal refuse, coal stockpile areas, un-reclaimed mine spoil, and waste sulfide rock." The opportunity to identify these 50 mining companies and their respective bactericide application sites is long past.

Hopefully, this investigation will preserve the locations and information for at least some of the sites where ATFO have been successfully controlled. Details of the case histories considered in this investigation follow.

2.1 Site 1 (1984) Route 43, Jefferson County, OH, USA

2.1.1 Site Description

This six-acre (2.4 ha) site called "Route 43" near East Springfield OH received "first generation" slow release bactericide products. Acid-base accounting data for this coarse coal refuse site is not available but it assumed that pyritic sulfur content of the refuse material was elevated. The sloping site was divided into two equally-sized parcels; after re-contouring, one parcel received a combination of liquid spray and controlled-release pellets. The remaining three-acre (1.2 ha) parcel

served as a control. Both parcels received six to eight inches (15 to 20 cm) of topsoil followed by fertilizer, agricultural limestone, seed, and hay mulch. (Maierhofer, 1988).

The toe of this sloping site was fitted with two perforated drainage pipes, one for each parcel (treated and control).

2.1.2 Evidence of Success

Seep chemistry and soil bacteria data collected three years after the treatment are provided in Table 1. Vegetation productivity data observed a decade after the bactericide treatment is provided in Table 2.

Table 1 - 1987 Route 43 Site Data (Maierhofer, 1988)

Parameter	Control	Bactericide-Treated
pH (S.U.)	2.6	5.9
Acidity (mg/L)	844	19
Aluminum (mg/L)	38.7	0.5
Iron	104	<0.2
Manganese	6.1	0.3
Sulfate	2,040	100
Specific Conductance	2,910 μ s	590
Vegetation health	“destroyed by seep”	“high quality vegetation”
TBFO populations in refuse sample	1.76×10^7	5.61×10^5
Heterotroph populations in refuse sample	6.43×10^5	3.47×10^7
Ratio of TBFO to Heterotroph population	1014:1	0.22:1

Table 2 - 1989 & 1994 Route 43 Site Data (Rastogi, 1996)

Parameter	Control	Bactericide-Treated
Biomass Production 1989 (1,000 kg/ha)	0 to 0.32	2.92
Biomass Production 1994 (1,000 kg/ha)	0 to 1.90	4.12
Aluminum (mg/L)		
Iron	No Flow from underdrains	No Flow from underdrains
Manganese		
Sulfate		
Specific Conductance		

The August, 2015 Google Earth™ image of this site (Lat. 45.45°N, Long. 80.87°W) does not exhibit evidence of seepage from either the control (southeast parcel) or the treated area (northwest parcel). However, the control parcel exhibits significantly more topsoil erosion than the treated parcel with the caveat that both parcels appear to be frequented by all-terrain or other similar vehicles, which can exacerbate soil erosion losses on steep slopes. The erosion losses at the toe of the control parcel (where the seepage pipe discharged) are especially visible and appear to worsen over time as shown in progressively older images of the site. Recall that the topsoil thickness placed over the treated and untreated parcels was only six to eight inches (15 to 20 cm).

The treated parcel is clearly out-performing the control parcel and the site is no longer monitored.

2.2 Site 2 (1990) Branchton Coal Refuse Disposal Area, Butler County, PA, USA

2.2.1 Site Description

In the early 1990s, this 39-acre (15.8 ha) actively-managed disposal site (Lat. 41.09°N, Long. 79.98°W) received coarse and fine-grained coal refuse with an average pyritic sulfur content of 13.1% with a neutralization deficiency of 444 tons (444 tonnes) per 1,000 tons (1,000 tonnes) of CaCO₃ equivalent (Parisi, et al. 1994 and Horneman, 2016). Despite placing a permit-mandated one-foot (300 mm) thick layer of 40% to 60% equivalent lime reject at a rate of 3,000 tons/acre (6,740 tonnes/ha) applied atop a four-foot (1.22 meter) thick lift of mixed fine and coarse refuse and other preventive measures, the facility underdrain seepage exhibited elevated acidity, iron, and manganese.

This situation was remedied with an application of an anionic surfactant solution comprised of:

- 200 pounds (91 kg) of 88% strength sodium dodecyl benzene sulfonate, and
- 800 gallons (3,028) liters of water.

This solution volume was applied to each acre (0.40 ha) of exposed refuse on a quarterly schedule. At closure, controlled release pellets were added at a rate of 600 lbs./ac (674 kg/ha) before the two-foot (61 cm) thick alkaline topsoil layer was placed and the area was reseeded. Spray applications commenced in early January 1991 (Parisi et al., 1994); the site was eventually closed and revegetated.

2.2.2 Evidence of Success

As shown in more detail in Figure 2 in Parisi et al. (1994), the immediate effects of the treatment were pronounced. Thirty (30) weeks after the first spray application with three additional subsequent applications, seepage acidity dropped 88% from peak values of 2,600 mg/L to steady state values of about 300 mg/L. During the same interval, iron decreased 82% from peak values of about 1,000 mg/L to steady state concentrations of about 180 mg/L. Lastly, manganese dropped 90% from about 50 mg/L to 5 mg/L. These improvements were sufficient to meet permit discharge requirements with the “treatment ponds” at the site (Parisi, et. al., 1994 and Parisi, 2016).

The reported post-treatment concentration of iron (300 mg/L), in the treatment ponds would certainly be evident in air photo imagery and this is indeed the case for Google Earth™ images for 2006, 2008, and 2010. Interestingly, the 2012 air photo image lacks a ‘yellowboy’ signature. Furthermore, it appears that the Pennsylvania Department of Environmental Protection is no longer monitoring the site. This would be deemed a “success” as previously defined.

2.3 Site 3(1987) North Fork Coal Mine, Wise County, VA USA

2.3.1 Site Description

Two coal seams were mined at this 150 ac (60.7 ha) site (Lat. 37.07° N, Long. 82.71 W) in the 1950s and 1960s using contour and mountain top removal strip mining methods. The mining pre-dated the 1977 surface mine reclamation law in the US. Overburden materials contained pyritic shales and weathered coal from cleanings and outcrop areas. The site was barren of vegetation and was found to be a major contributor of acid loading and silt to the North Fork of the Pound River Reservoir which was a drinking water supply for 1,700 people in the surrounding communities. The reservoir also was a popular recreational destination for about 100,000 annual users (Abbott, 1990).

Pre-reclamation water chemistry exhibited classic ARD characteristics:

- pH <3.4 s.u.
- acidity – 1,000 mg/L
- manganese - 125 mg/L
- iron – 20 mg/L,
- aluminum – 60 mg/L

About 25% of the site area received both ProMac spray and controlled release pellets at a cost in 1987 of about \$US104,000. This was about 2.8% of the total cost of reclamation (\$US3.7 million). About 1.1 million cubic yards (840,000m³) of pyritic overburden were moved. No application details are available other than the spray and pellets were applied with hydro-seeding equipment. (Abbott, 1990).

2.3.2 Evidence of Success

This site won the first-place award in Virginia's 1989 "Take Pride in America" program which recognized outstanding achievement in the nation's public lands, and natural and cultural resources. An inquiry directed to the Virginia Department of Minerals, Mining and Energy (DMME) revealed that details of this site are lost in the mists of time; the only information available about the project in the digitized archives was a pre-construction map that identified disturbed areas and sub-watersheds. The site does not appear to be monitored. A review of Google Earth images dating back to 1995 (eight years after project completion) reveal a site with little evidence of erosion and broad-based reclamation success. As of 1990, "A good stand of vegetation was achieved after two years, even on difficult steep slopes. This reclamation project has resulted in significant water quality improvement in the [North Fork of the Pound River] reservoir in which aquatic populations have recovered." (Abbott, 1990). More recent Google Earth images (2013) did not exhibit any evidence of ARD in ponds or streams immediately down gradient from the site.

2.4 Site 4 (1986) Dawmont Coal Refuse, Harrison County, WV USA

2.4.1 Site Description

In 1986, two pyritic (up to 15.6% pyritic sulfur) coarse coal refuse piles comprising about 250,000 cubic yards (191,000 m³) of material dating from the 1920s to 1960s were un-reclaimed and acidic runoff was impacting the nearby West Fork River. In 1987, this 36 ac (14.6 ha) site (Lat. 39.32° N, Long. 80.34° W) was regraded and it received a "small quantity" of lime after an application of ProMac powder and controlled release pellets. A soil cover from 12 to 18 inches (30 to 45 cm) thick that followed was fertilized, seeded, and mulched with straw. (Sobek, et al., 1990).

A one-acre (0.4 ha) portion of the site did not receive the bactericide treatment and served as a "control".

2.4.2 Evidence of Success

Within two years of project completion, the soil pH of the treated area was near 5 s.u. while the untreated control never exhibited a pH higher than 3 s.u. In 1988, the site garnered a Reclamation Award from the West Virginia Mining and Reclamation Association and the West Virginia Department of Energy. The site was covered with a "lush growth of birds-foot trefoil... and the acids that once found their way into the West Fork have been brought under control". (Land and Water, ND – circa 1989).

A summary of parameter improvements observed at the Dawmont Site is provided in Table 3.

Table 3 – Dawmont Site Data (Sobek et al., 1990)

Parameter	Background Ranges	Year 1988	Year 1989	Year 1990
pH	2.1 – 2.5			
Acidity	2.8 to 20 gr/L	95.8%	95.7%	95.8%
Specific Conductance	4650 to 18500 µmhos/cm	89.9%	86.5%	91.2%
Sulfate	2.4 to 3.1 gr/L	90.5%	90.1%	90.8%
Total Iron	161 to 3,600 mg/L	96.1%	93.8%	97.3%
Manganese	8.5 to 290 mg/L	74.8%	61.1%	85.6%
Aluminum (mg/L)	418 to 1,300 mg/L	85.4%	82.2%	88.5%

A review of Google Earth images dating back to 1995 (eight years after project completion) reveal a site with little evidence of erosion and broad-based reclamation success. Interestingly, the 2013 image suggests a fracking operation was underway on the site.

2.5 Site 5 (1984) Norton Coal Refuse Site, Randolph County, WV USA

2.5.1 Site Description

From 1984 to 1985, a 25 acre (10 ha) pyritic coarse coal refuse pile site (Lat. 38.93° N, Long. 79.96° W) was regraded and treated with bactericide (spray and second-generation pellet form) before receiving a soil cover layer only six inches (15 cm) thick (Rastogi & Bohac, 1987).

A one-acre (0.4 ha) portion of the site did not receive the bactericide treatment and served as a “control”. The site was fitted with 20 moisture sampling lysimeters to monitor the effects of the treatment in the vadose zone.

2.5.2 Evidence of Success

The results of the vadose zone monitoring as reported by Sobek and Horowitz (1987) were summarized by Rastogi & Bohac (1987). Attempts to procure the original 1987 Sobek and Horowitz report from the State of West Virginia were unsuccessful. The verbatim summary results reported by Rastogi & Bohac (1987) follow.

- Microbiology: The acid producing bacterial population averaged 200 time greater in the control area than in the treated areas.
- Water Quality: All parameters in the treated areas were better than those in the control area. Of particular significance are over 75% decrease in sulphates, 94% decrease in manganese, and 76% decrease in aluminum in the treated areas, compared to 38% decrease in sulphates and slight increase in aluminum in the control.
- Refuse: Refuse pH in the treated area was 6, compared to 4.4 in the control.
- Vegetation: The site shows excellent dense vegetation in its second year of growth. Long-acting controlled release bactericide systems greatly reduce the population of the acid-producing bacteria causing a large decrease in acidity and metals solubilization. This promotes the growth of heterotrophs necessary for establishing healthy revegetation. The Norton site has been stabilized with a luxuriant growth of vegetation, indicating the ProMac Systems treatment has already started the site back on its road to full recovery.

A review of Google Earth color images revealed an orange plume of suspected iron oxyhydroxide in the Tygart Valley River down gradient from where the drainage from the Norton site watershed enters in 2003. It is unknown whether the Norton site or a nearby site was the source of the plume. Subsequent images (2007, 2009, 2010, 2011, and 2013) do not suggest the presence/influence of acidic drainage.

2.6 Site 6 (2004) California Gulch Superfund Site, Lake County, CO USA

2.6.1 Site Description

Metal mining in Lake County, Colorado (Lat. 39.2° N, Long. 106.4° W) over a 130 year period in the late 1800s to 1900s resulted in the release of pyritic tailings and water with high metals concentrations via California Gulch into the Upper Arkansas River (UAR). The tailings deposits (up to about four feet [1.2 m] thick) resulted in a ten mile (15) km long barren reach of the UAR that exhibited continuous erosion and re-deposition of tailings and the generation of acid salts that were chronically washed into the river, especially in response to storm events. The site was added to the Superfund list in the US in 1983; the UAR was designated Operable Unit 11 (OU-11).

Vegetation and the soil community were limited by “high metals concentrations, low pH [1.5 to 4.5 s.u.], insufficient macro- and micro-nutrients, poor physical properties, and reduced water holding capacity” (EPA, 2011). Clearly, pyrite oxidation in the metal mine tailings was the source of the problem. Removal and capping of the tailings in an off-site repository was considered and rejected as being too disruptive and expensive. In situ stabilization was the preferred alternative.

The subsequent research focused on developing a revegetation strategy that repopulated the flood plain with a sustainable plant community that reduced erosion and allowed the bottom land to return to its historic land use, livestock grazing.

Vegetative test plots using various soil amendments were assessed (Maxemchuk, 2002). Based on two years of test plot observations, a remedy was selected that utilized lime neutralization and municipal biosolids as the primary soil amendments. Remarkably, microbiological studies of the soils in the test plots did not include assessments for ATFO populations even though the pyrite content of the soils was elevated (USEPA, 2011).

The OU-11 remediation effort commenced at a demonstration level in 2008 on about 20 acres (8 ha) of fluvial deposits and 160 acres (65 ha) of irrigated meadowland. Other OU-11 remediation efforts followed.

2.6.2 Evidence of Success

In 2014, the 102 mi. (164 km) long Arkansas River was classified as a Gold Medal Trout Fishery by the Colorado Division of Wildlife (Willoughby, 2014). This included the mining impacted headwaters around Leadville; i.e., OU-11. In 2016, this condition appears to remain sustainable; there is no visual evidence of iron contamination in the UAR which was the focus of the remediation efforts described above.

2.7 Site 7 (1995) – Fisher Coal Mine, Indiana County, Pennsylvania, USA

2.7.1 Site Description

Plocus & Rastogi (1997) sequentially injected solutions of caustic soda (NaOH) and sodium lauryl sulfate at the Fisher Coal Mine in Pennsylvania USA in 1995. The potentially acid generating (PAG) rock zone in a backfilled coal pit had been identified using geophysical techniques. The site was fully revegetated at the time of the two-step caustic/bactericide application through a network of shallow and deep injection boreholes that mimicked the pattern typically found in a heap leach pad.

2.7.2 Evidence of Success

The effects of the injection process in the PAG zone were dramatic. Chemistry of a toe seep at the site improved enough within 30 days that chemical treatment of the ARD was no longer required. In 2016, two decades later, this is still the case. In fact, the seepage chemistry is suitable enough to be discharged as-is without constructed wetland polishing and it meets the permit requirements (Gusek and Plocus, 2016). Bond release for the site is pending.

If the effects of the bactericide are supposed to be temporary, what can explain the persistence of the beneficial effects of the two-stage application of caustic and bactericide? Gusek and Plocus advanced the following explanations:

- 1) The initial “flooding” injection of caustic neutralized the residual acidity in the PAG mine waste so that the subsequent application of bactericide was “protected” from chemical attack;
- 2) The bactericide solution (2% sodium lauryl sulfate) would have followed the preferential pathways established during the stage 1 injection of caustic to inhibit the activity of the acidophilic community; and
- 3) The well-established revegetated surface of the site provided a steady supply of bacteria inhibiting organic acids (and continues to do so) which appears to have suppressed the “reinfection” of the site that would have otherwise occurred.

3 A PATHWAY TO WALK AWAY

A “Walk-Away” mine land reclamation/remediation scenario is the holy grail of any mining company or government agency. To achieve this status, a site must involve:

- Little to no maintenance,
- Infrequent inspection,
- Little or no long-term monitoring, and

- Return to a land use that is a benefit to society.

The seven case histories previously discussed demonstrate that walk-away successes are possible even in situations where pyritic waste has already been intensely involved in microbial/ATFO activity. However, a “silver bullet”, one size fits all approach will not be successful unless it is followed by the development of a robust vegetative cover that delivers a steady dosage of antibacterial organic acids. The science and engineering behind revegetation of disturbed mine land is well documented in three-decades of the proceedings of the American Society of Mining and Reclamation (see www.asmr.us). However, the sequential applications of organic and inorganic amendments that suppress ATFO activity have yet to be combined in a manner that preconditions a problematic site to reap the benefits subsequent vegetation. Design considerations for site “preconditioning” follow.

3.1 Controlled Application of Antibacterial Reagents

With the lack of ProMac or similar controlled release technologies, alternative SLS delivery methods are required. Fortunately, heap leaching practices for gold and silver ore matured in the western USA in the early 1970s and are now used world-wide. This concept was described by Gusek (2015) for the application of biochemical reactor effluent or waste milk (organic bactericides) but it might also be used for the controlled delivery of inorganic/surfactant bactericides such as SLS.

Antibacterial reagents can also be delivered using temporarily stable foams as described by Gusek et al. (2012). The reagents can be solid, liquid, or gaseous. As SLS is a common foaming agent, the foam itself is antibacterial.

However, one must consider the strength of the bactericide solution in any controlled delivery design. Elevated concentrations of SLS, for example, may adversely affect desirable heterotrophic bacterial communities as well as ATFO (Clark, 2015). This design consideration supports the concept of prolonged application of low dosage bactericides; it is probably another reason that the ProMac slow release pellets worked as well as they did.

3.2 Advances in Revegetation Technology

While much has been accomplished with regard to revegetating drastically disturbed lands, advancements continue. Examples could include genetically-modified plants that might capitalize on soil characteristics that are typically toxic to natural plant species to gain a vegetative foothold in challenging environments. Also, the use of biochar (Harley, 2011) as a soil amendment has potential to increase soil cover production by sequestering plant nutrients/fertilizers in a way that is not easily rinsed out by precipitation events but is still extractable by plants. Establishing a robust vegetative cover should accelerate site recovery and suppress ARD more quickly than waiting for natural plant community succession.

3.3 Merging of Different Technologies

The engineer’s toolbox of ARD suppressing technologies has increased in breadth since the introduction of bactericides about three decades ago. Unfortunately during this period, the ARD suppression “industry” per se appears to have acquired a “vendor” perception where a specific product is advocated for nearly every situation. As ARD has been termed a worldwide bacterial infection (Gusek 2012), it seems that another medical analogue is appropriate: some ARD suppression practitioners might be analogous to medical doctor *specialists* who are proficient at healing patients with a specific malady rather than primary care physicians who view a patient holistically. From an engineering perspective, remediation of ARD requires a 21st century “general practitioner” who can merge the available technologies into a coordinated assault on the ATFO community at a given site or in a given situation.

This assault might include:

- a primary application of SLS bactericide to decimate the ATFO community followed by
- an application of waste milk or other organic amendment (with inoculant) to establish a competing heterotrophic bacterial community finally followed by

- the establishment of a vibrant and sustainable vegetative cover to maintain the heterotrophs.
- If properly designed and engineered, this could be a promising “Pathway to Walk-Away” for sites plagued with chronic ARD.

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